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Mat. Res. Soc. Symp. Proc. Vol. 692 © 2002 Materials Research Society H1.1

Luminescent Characteristics of InGaAsP/InP Multiple Quantum Well Structures by Impurity-Free Vacancy Disordering

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ABSTRACT

InGaAsP/InP multiple quantum wells have been prepared by Impurity-Free Vacancy Disordering (IFVD). The luminescent characteristics was investigated using photoluminescence (PL) and photoreflectance (PR), from which the band gap blue shift was observed. Si_3N_4, SiO_2 and SOG were used for the dielectric layer to create the vacancies. All samples were annealed by rapid thermal annealing (RTA). The results indicate that the band gap blue shift varies with the dielectric layers and annealing temperature. The SiO_2 capping was successfully used with an InGaAs cladding layer to cause larger band tuning effect in the InGaAs/InP MQWs than the Si_3N_4 capping with an InGaAs cladding layer. On the other hand, samples with the Si_3N_4-InP cap layer combination also show larger energy shifts than that with SiO_2-InP cap layer combination.

INTRODUCTION

In fabricating luminescent devices for integrated optoelectronic and photonic application, InGaAsP/InP multiple quantum well (MQW) structures have attracted research interests. Post-tuning of optical band gap energy can be achieved from these MQW structures, which posses the advantage to avoid the complicated post growth processing. Several technical approaches have been explored to achieve this purpose, including (1) Impurity Induced Disordering (IID) [1,2], (2) Implant Induced Composition Disordering (IICD) [3-6], and (3) Impurity-Free Vacancy Disordering (IFVD) [7,8]. Among them, IFVD technique shows more promising because it can keep high crystal quality and low optical propagation loses as well as it does not introduce free-carrier concentration. IFVD, utilizing a dielectric layer such as SiO_2 and Si_3N_4 as Ga sink at elevated temperature, could result in the redistribution of Ga vacancies in MQWs to enhance the quantum well intermixing and thus to enhance the luminescence [9,10].

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In this paper, a systematic investigation on luminescent characteristics of InGaAsP/InP MQW system using SiO_2, Si_3N_4 and SOG (spin on glass) as dielectric layers in IFVD is reported. Photoluminescence (PL) was measured by a Fourier Transform Infrared (FT-IR) PL system. Photoreflectance (PR) measurements on these samples were used to investigate further the behavior of band gap blue shift. To our knowledge, there was no report published with measuring band gap blue shift by PR for this material system yet. We found that the different combinations of cladding layer and dielectric layer, such as InP-SiO and InP-SiN, also affect the band gap luminescent characteristics, which was also rarely reported.

EXPERIMENT

Two typical samples were chosen in this paper. Both samples A and B are InGaAsP/InP laser structures, consisting of three quantum wells, designed to emit at wavelength of 1.57 μm and 1.55 μm, respectively. They were grown by Gas Source Molecular Beam Epitaxy (GSMBE). The detail structures of samples are shown in Table 1, in which "1.15Q" means "InGaAsP layer with the bandgap wavelength of 1.15 μm", and "ud" does "un-doped". Sample A was cut and divided into three groups with capped dielectric layers of SiO_2 and Si_3N_4 by PECVD and SOG by spin coating at 3000 rpm for 45 second. The thickness of all the dielectric layers is about 200 nm. Samples with the SOG cap were then baked at 200 °C for 2 hours under pure nitrogen ambit protection. Sample B was divided into two groups remarked B1 and B2. B2 was etched InP cladding layer away using corrosive solution ($HCl:H_3PO_4$=1:1). Then samples B1 and B2 were deposited SiO_2 and Si_3N_4, respectively, by PECVD. The thickness is also about 200nm.

Table 1. Schematic layer structure of the InGaAsP/InP MQW samples studied.

Sample A	Sample B
He*-InP p=1e18 100nm	100nm InP (ud)
InP p=6e17, 25nm	5nm InGaAs (ud)
1.15Q InGaAsP p=5e17, 80nm	200nm InP p=1e18
1.24Q 70nm	200nm InP p=5e17
1.58Q 5nm	40nm He* InP p=5e17
1.24Q 10nm	5nm InP p=5e17
1.58Q 5nm	100nm 1.15Q p=5e17
1.24Q 10nm	60nm 1.24Q (ud)
1.58Q 5nm	3*5nm QW's ; 2*10nm Barriers (QW~$In_{0.758}GaAsP_{0.17}$)(Barrier~$In_{0.758}GaAsP_{0..475}$)
1.24Q 70nm	30nm 1.24Q (ud)
1.15Q n=5e17 80nm	30nm 1.15Q n=5e17
InP n=1e18 500nm	500nm InP n=1e18
n+ InP subtrate	n+ InP Substrate

After the GSMBE growth, samples were then annealed in a rapid thermal annealing (RTA) furnace at the temperature ranged from 650 °C~850 °C in 50 °C steps. The annealing time for all samples was kept for 30 seconds. During the RTA the samples were covered with a piece of

semi-insulating-GaAs face to face to minimize the decomposition of InP and possible contamination. All annealing processing are under the pure nitrogen protection.

Photoluminescence measurements were performed at the temperature 300K. The excitation source was an Argon ion laser with the wavelength of 514.5 nm. The Photoreflectance (PR) spectra were measured at the optoelectronic laboratory of Nankai University. The modulation source was a He-Ne laser with the wavelength of 632.8nm.

RESULTS AND DISCUSSION

Room temperature PL spectra are shown in Figure 1 for the as-grown sample A and disordered InGaAsP multi-quantum well structures after RTA at 800^0C for 30s with SiO_2 and Si_3N_4 encapsulating layer, respectively. The peak position of the PL spectrum for the as grown sample A is at 1.571 m (0.789 eV), corresponding to the electron transition from the first level of electronic subband to the first level of heavy hole (E1-HH1) and light hole subband (E1-LH1). From the figure 1, we can find that the band gap blue shift depends on the dielectric layer. The sample A with a Si_3N_4 capped layer obtained larger blue shift. In order to find the dependence of the band gap blue shift on the annealing temperature, the samples covered with Si_3N_4, SiO_2 and SOG were annealed at the temperature of 650, 700, 750, 800 and 850^0C, respectively. Figure 2 shows the annealing temperature dependence of band gap shift. It can be observed that the band gap of PL peak varies with the RTA temperature. For low annealing temperature range of 650~750^0C, the PL peak has little change, however, when the annealing temperature was beyond 750^0C, the PL peak moves to short wavelength evidently.

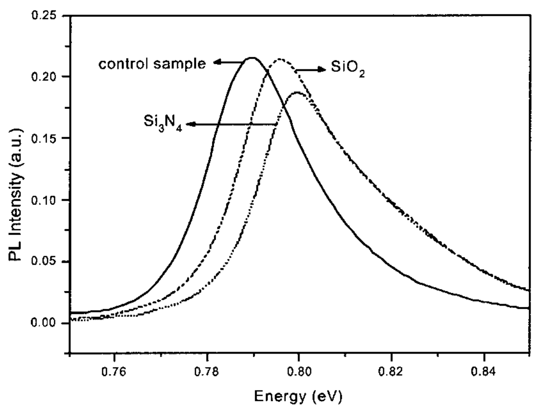

Figure 1. The PL spectra of the control sample and SiO_2, Si_3N_4 covered samples.

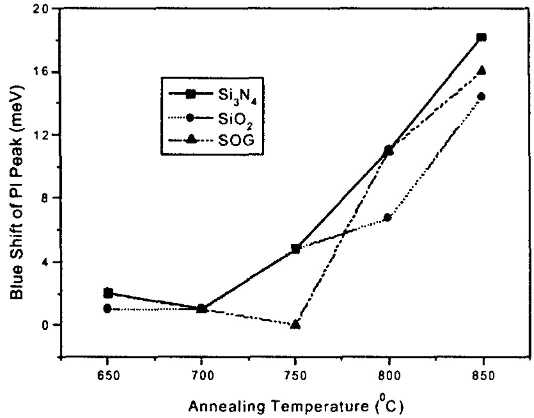

Figure 2. The temperature dependence of blue shift for different dielectric covered samples.

On the other hand, we also performed photoreflectance (PR) measurements in accordance with the results of PL spectra, as shown in Figure 3. It shows that PR results are consistent with the PL results. This indicates that PR can be used as a supplementary way to study the luminescent characteristics of the band gap shift. Furthermore, PR spectra can provide some other information, for example, some detailed data about different layer luminescent characteristics through analyzing PR spectra, which to be done in a separate paper.

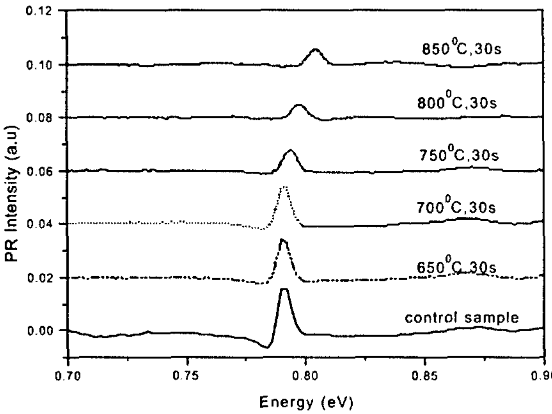

Figure 3. Band gap blue shift measured by PR with different annealing temperature.

In order to find the effects on the combination of the cladding layer and dielectric covered layer, the annealing temperature dependence of the bandgap blue shift for sample B1 and B2 with different dielectric layers were further studied, based upon the PL data. Sample B1 has an InP cladding structure, and sample B2 has an InGaAs cladding layer. Both samples B1 and B2 have the same MQWs except for the cladding layer. These two types of samples were measured under the same experimental condition, to examine their band gap blue shift. Figure 4 shows the dependences of the blue shift PL peak on the annealing temperature, caused by different covered layer of Si_3N_4 and SiO_2, respectively. It can be observed that the induced blue shift from the sample with the InP-Si_3N_4 combination is larger than that with the InP-SiO_2 combination. For example, the blue shift of the sample with the InP-Si_3N_4 cap layer combination reaches 50 meV at 850^0C, but the blue shift of the sample with the InP-SiO_2 cap layer combination is only 40 meV at the same annealing temperature. On the other hand, the combination of InGaAs-Si_3N_4 covered layer caused 20 meV, however the combination of InGaAs-SiO_2 reached 43meV. From these results, we can conclude that the combination layer of InP-Si_3N_4 or InGaAs-SiO_2 can create larger band gap blue shift than the combination of InP-SiO_2 and InGaAs-Si_3N_4 ones. The reason for these experimental results is not very clear, but in our opinion, it can be explained as follow: The vacancies are produced in both group III and V. It is known that in GaAs material the following reactions are prompted to produce large number of vacancies at the interface:

$$4GaAs + 4SiO_2 \Leftrightarrow 4Ga + 2As_2O_3 + 3Si \quad (1)$$

$$As_2O_3 + 2GaAs \Leftrightarrow Ga_2O_3 + 4As \quad (2)$$

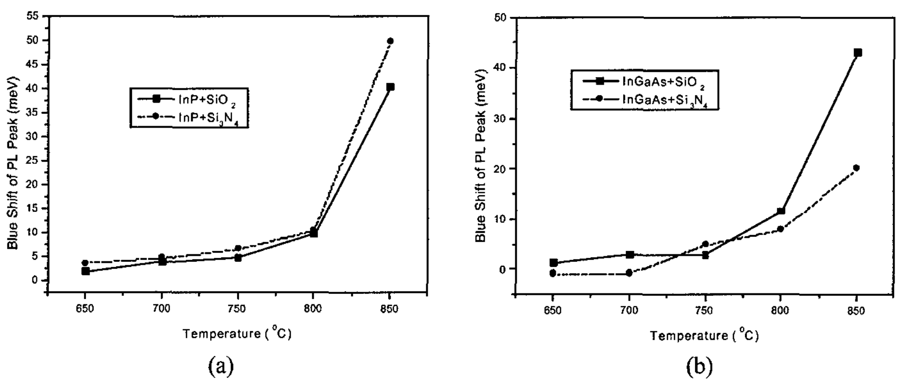

Figure 4. The temperature dependences of blue shift for the samples with (a) InP-SiO_2 and InP-Si_3N_4 combination layers, and (b) InGaAs-SiO_2 and InGaAs-Si_3N_4 combination layers.

Our results indicate that the vacancies generated by the InP-SiO_2 combination are less than that by the InGaAs-SiO_2 combination layers because of the absence of Ga. As for the group V vacancies, we can not provide the detailed reactions as to how the vacancies are produced. This may be the reason for the effects on the combination of the cladding layer and dielectric layers.

CONCLUSION

In conclusion, we have studied the dependence of the band gap blue shift on the annealing temperature and dielectric layers from the InGaAsP/InP multiple quantum wells prepared by Impurity-Free Vacancy Disordering (IFVD). Both PL and PR results, which are consistent each other, showed that this band gap blue shift increases with the annealing temperature for all samples. To our knowledge, this is a first report on the band gap blue shift measured by PR. Our results indicate that PR can also be used as a supplementary way, in addition to PL, to study the band gap blue shift. On the other hand, to obtain larger energy shift the optimal selected cap layer combination is necessary. From our experiments the combination of InP-Si_3N_4 or InGaAs-SiO_2 is better than the combination of InGaAs-Si_3N_4 or InP-SiO_2.

ACKNOWLEDGMENTS

The authors would like to thank Dr. B. Robinson at McMaster University Canada for providing the GSMBE samples. This project is supported by the Nature Science Foundation of China (NSFC) with a contract number of 69886001.

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